March 28, 1911.

Sir WILLIAM ALLCHIN, Vice-President of the Section, in the Chair.

The Electrocardiographic Method and its Relationship to Clinical Medicine.

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A BRIEF DESCRIPTION OF THE GALVANOMETER METHOD.

GALVANOMETERS, instruments constructed to measure electric current, and electrometers, instruments constructed to measure electric potential, have been in general use in the physiological laboratory for many years. The time at my disposal will not permit me to detail the history of our knowledge of these instruments. It will be convenient if I turn immediately to the latest development, the introduction of the new "string galvanometer" of Einthoven. It is an instrument which, on account of the quickness of its response, its sensitivity and the ease with which it is managed, is rapidly superseding all other instruments of its class. It consists of a powerful electromagnet, the separate poles of which are closely approximated, and leave between them a narrow chink (fig. 1). In this chink an extremely fine fibre (of platinum or silvered quartz) is suspended. The principle of the instrument is simple. When you pass an electric current through a conductor lying in a magnetic field, conductor and magnet react upon each other, and if one system is fixed and the other is movable, the latter (the movable system) is deviated in a definite direction. In the string galvanometer the magnet is fixed, the string is slack and flexible; the string is the movable

[1] Working under the tenure of a Beit Memorial Research Fellowship.

system, and it deviates when a current is passed through it. The quickness and sensitivity of the instrument depend upon the lightness of the fibre and upon the strength of the magnetic field. The strength of the magnetic field of the string galvanometer and the lightness of the fibres are such that accurate measurements may be made of very minute currents. When the instrument is properly adjusted the deviation of the string is directly proportionate to the strength of current passed through it.

I shall pass over the history of our knowledge of the electric changes which accompany the contraction of muscle and the heart-beat,

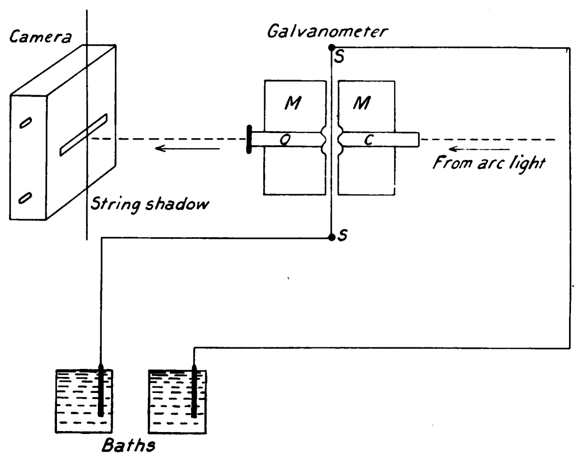

FIG. 1.

A simple scheme showing the arrangement of the apparatus used in securing electrocardiographic curves. It consists essentially of the galvanometer, arc light and camera. The galvanometer consists of a powerful electromagnet, *M M*, between the poles of which is a slit in which lies a string, *S S*, of extreme tenuity and composed of platinum or silvered quartz. The string is connected to a circuit which is completed by the patient, whose limbs are immersed in the baths. The beam of light from the arc light falls through the condenser, *C*, and the shadow of the moving string is projected by means of the microscope, *O*, on to the camera. The shadow of the string lies vertically, the slit of the camera lies horizontally, and the movements of the shadow are at right angles to it. Photographic paper is unwound by means of a mechanical arrangement behind the slit.

and turn to the more important facts now known to us, and which immediately concern us.

When a contraction is started in a muscle strip, be it somatic or cardiac, the point at which activity first manifests itself becomes relatively negative to all other points of the strip surface. The activated or contracting end stands in electrical relationship to the inactive end of the strip, as does the zinc terminal of a Daniel cell to the copper terminal. If the ends of the strip are connected to a sufficiently sensitive galvanometer the electric change in the muscle is recorded by a deviation in a given and known direction. Now when a strip of muscle contracts the state of contraction or activity travels from one end of it to the other; at first the proximal or stimulated end is active, and consequently relatively negative to the distal end. Later, as the contraction wave passes to the distal end and the proximal

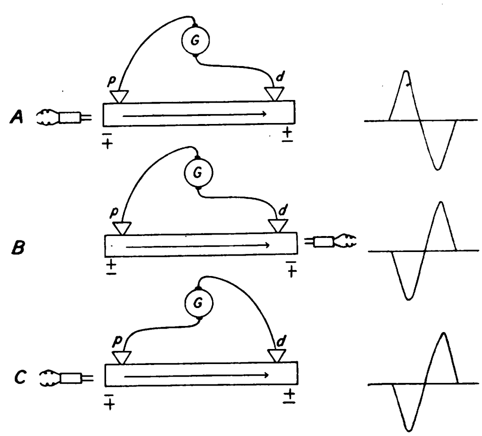

FIG. 2.

A diagram illustrating certain principles of electrocardiographic work. In *A*, *B* and *C* straight strips of muscle are diagrammatized, from the ends of which leads are taken with non-polarizable electrodes to the galvanometer, *G*. In *A* the muscle is stimulated to the proximal end, *p*, and the contraction travels from *p* to *d*. While the contraction is at *p*, *p* is negative to *d*. When the contraction reaches *d* and subsides at *p*, *d* becomes negative to *p*. A diagrammatic representation of the curve obtained is shown to the right of the figure. In *B* the muscle is stimulated at the distal end, and the events are reversed. The contraction passes from *d* to *p*, *d* is first negative to *p*, and later positive to *p*. The type of curve shown to the right is the reverse of that given in A. In *C* the stimulation and direction of the contraction wave are the same as in A, but the electrodes are reversed; *p* is first negative to *d*, and later positive. The type of curve is the same as that yielded by *B*.

end becomes quiescent the electric condition is reversed, and the galvanometer shows a deviation which is contrary in direction to the original deviation. The complete electric effect is termed a diphasic effect. Now the actual shape of the curve need not delay us, but it is important for us to note that it is dependent upon two factors: first, the point at which the contraction wave starts, and secondly the relationship (in space) of the muscle mass (and all its parts) to the leading off electrodes. Stimulate the muscle at the opposite end and reverse the series of events of the contraction wave, and you obtain a complete and exact reversal of the electric effects. Maintain the point of stimulation and reverse the electrodes, you obtain a similar result. These two facts illustrate the essential principles which must be constantly borne in mind in dealing with the electrocardiogram (fig. 2).

What is the electrocardiogram, and how is it secured? An electrocardiogram is a photographic representation of the electric changes occurring between any two points of the body surface as a result of the heart-beat. It may be obtained by means of special electrodes applied to the base and apex of a heart under experimental conditions. The lead from base and apex of the heart is used because it represents, approximately, the general direction in which the muscle contracts; any other lead will yield an electrocardiogram, but it is essential to fix upon one or more definite leads for the sake of uniformity and comparison, and base-apex leads are usually employed. The electric changes at base and apex of the heart are not confined to them, they spread into the surrounding tissues in contact with them. In human galvanometric work the instrument is usually connected to what closely corresponds to a base-apex lead; a lead from the right arm and left leg is utilized, a lead equivalent to one from the right shoulder and left groin. Others are adopted, but I intend to confine attention to this single lead for the time being.

It is sufficient to connect the right arm and left leg of a patient by means of suitable electrodes, for example, baths of salt water (fig. 1), to the ends of the string (S S) of the galvanometer, to set this string in motion. The movements are minute, but may be magnified and projected by means of a microscope (O C) driven through the poles of the magnet (M M) on to a convenient photographic screen (fig. 1). A beam of light, falling through a condenser upon the string, projects the shadow through the objective. The shadow lies vertically, and at right angles to a slit, behind which a sensitive film is moved on rollers. The shadow moves from side to side across the slit, and hiding the sensitive paper from the light, leaves the impress of its movements upon it.

Up to the present I have described to you the working principles of the instrument, and you have the general idea of the manner in which records are obtained. I have also spoken briefly of the electric changes which accompany contraction in muscle, and have drawn your attention to two important considerations. The curve which is obtained from a contracting muscle depends upon the lie of the muscle in relationship to the leading off electrodes. We need not consider this factor further, for I propose to speak of the single lead—that from the right arm and left leg. Of far greater importance to us at present is the fact that the shape of curve depends upon the direction taken by the wave of contraction in the heart muscle itself.

We may proceed to consider the form of the physiological electrocardiogram, and I shall pass from this to a description of a number of selected electrocardiographic curves of pathological form. The instances given must be regarded only as illustrative.

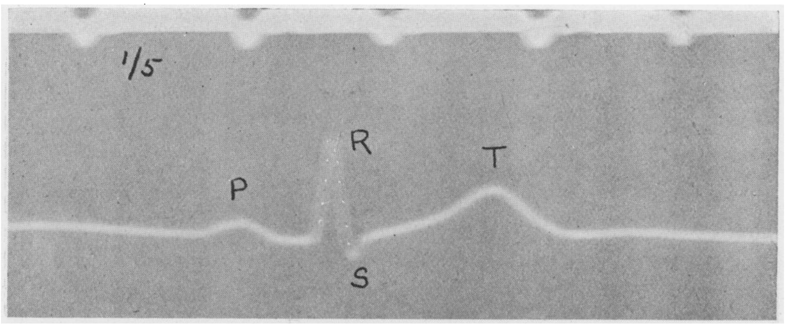

FIG. 3.

An electrocardiogram of a single normal heart-beat. As in all the figures, the upper line is a time marker showing fifths of seconds. The electrocardiogram consists of variations P, R, S, and T, of which P represents the auricular contraction and R, S, and T the ventricular contraction.

THE PHYSIOLOGICAL ELECTROCARDIOGRAM.

As has been stated, the physiological electrocardiogram is obtained by placing the limbs of the subject investigated in baths of salt solution and connecting these baths to the indicator—the string of the galvanometer. The curve photographed is a complicated one and consists of a number of variations. They have been labelled in a purely empiric fashion with the letters P, Q, R, S and T (figs. 3 and 4).

We may divide the whole curve into two strictly separate portions —P, on the one hand, Q, R, S and T, on the other—and I have termed these separate portions the *auricular and ventricular complexes* respectively. P is the result of contraction of the two auricles, Q, R, S and T are the outcome of contraction in the two ventricles. Dealing with the ventricular complex (Q, R, S and T), the dips Q and S are usually inconspicuous, while R and T are prominent. It will simplify matters if attention is concentrated upon the more conspicuous variations, P, R and T; of these P is auricular, and R and T are ventricular. The relationship of these variations to the events of cardiac contraction has been definitely ascertained experimentally. The shortening of the ventricular muscle commences a very small fraction of a second after the commencement of R and finishes a small fraction of a second after the subsidence of the broad wave T.

We need not enter into the hypotheses which attempt to explain the constitution of this electrocardiogram, but may rest satisfied at the

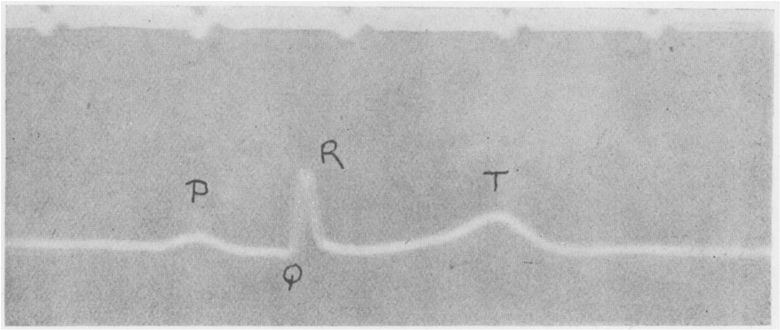

FIG. 4.

A normal electrocardiogram showing P, the auricular representative, and Q, R, and T, ventricular representatives.

present time with the following facts. It represents the electric change in a base-apex lead of a normal mammalian heart, and represents the contraction of the several parts of the cardiac musculature *in a definite order or sequence.* The mammalian heart-beat starts at the junction of superior vena cava with auricle, and the contraction spreads from this point and courses through the auricle to the tissue which joins auricle and ventricle, namely, the auriculo-ventricular bundle. Reaching this tissue the impulse is conveyed along the two divisions of the tract and is distributed through an elaborate arborization and Purkinje network to the ventricular musculature. Let me emphasize the fact that the normal auricular complex (P) indicates in a perfectly decisive manner the origin of the heart-beat in the neighbourhood of the superior cava; that is a conclusion which we are forced to accept as a result of experimental observations which I cannot now detail. Let me lay equal stress upon the fact that the ventricular complex (R and T, or Q, R, S and T) indicates a ventricular contraction started by an impulse which reaches it through the *normal field of reception*, namely, the arborization of the junctional tissues. It is only the contraction excited in this manner, i.e., through the physiological paths, which gives rise to a curve of the form described. The importance of these facts will be more obvious at a later stage, and in stating them I am merely elaborating the principle which I stated to you when we considered the simple strip of muscle. The shape of the curve depends upon the direction of contraction, *it consequently depends upon the point of origin*

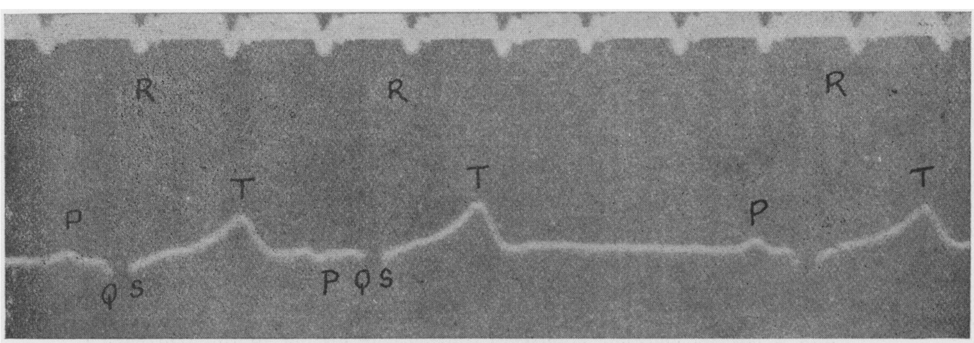

FIG. 5.

An electrocardiogram from a patient showing a premature contraction arising in the auricle. The first beat of the figure shows variations P, Q, R, S and T. They are of normal outline. The second cycle of the figure is the abnormal one. The auricle and ventricle are represented; the ventricle yields a perfectly normal complex, Q, R, S and T. Directly preceding the ventricular contraction, which is premature, is the representative of the abnormal auricular contraction, P. It may be compared with that of the preceding cycle. The shape of P in the abnormal cycle demonstrates that the auricular contraction has arisen at a point removed from the pacemaker. The third cycle of the figure occurs after a long pause and is normal in every respect. ($\times \frac{2}{3}$.)

of such contraction. Let us take two examples which illustrate this principle, the premature contraction which arises in auricle or ventricle respectively.

The Premature Auricular Contraction.—You are aware that a pulse may be irregular as a consequence of isolated disturbances occurring at intervals far removed from each other. These disturbances, often spoken of as *intermittences*, are usually the result of *pathological impulse formation* in the heart, and the abnormal impulses may arise in auricle and ventricle, and so far as we know in any part of them. Now, if the premature beat arises in the auricle, it causes and is succeeded by a premature ventricular contraction. In the electric curve it consequently gives rise to an auricular and to a ventricular complex. Except in exceptional instances, which I do not propose to consider, the ventricular complex is a duplicate of the ventricular complex of the normal and rhythmic beats in the same case; and this might have been anticipated, for we know that the impulse generated by the abnormal premature auricular contraction can only spread to the ventricle along the normal paths. The auricular complex of the abnormal beat, on the other hand, has a very variable form,

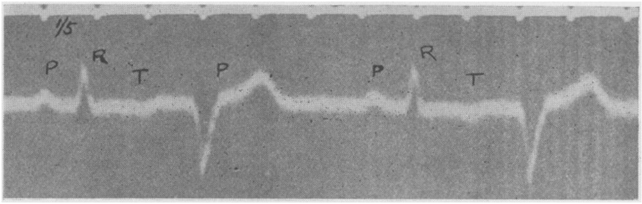

FIG. 6.

From a patient showing premature contractions arising in the ventricle. Each normal cycle is followed by an abnormal cycle. Each normal cycle is represented by the usual variations P, R and T, and is followed by an abnormal cycle representing the ventricular contraction. The abnormal cycle consists of two main variations, one in the downward, the second in the upward direction. The sequential auricular contraction falls in the centre of the premature ventricular contraction. The type of premature contraction shown arises in the apical or left portion of the ventricular musculature. ($\times \frac{2}{3}$.)

and rarely duplicates the normal auricular complex of the same case. The reason for this is evident. The beat has started, not at the normal pacemaker, the junction of superior cava and auricle, but at some other point, and the contraction *in the auricle* has taken an abnormal course (fig. 5).

The Premature Ventricular Contraction.—When a premature contraction arises in the ventricle the abnormal contraction is confined to this chamber. There is no disturbance of the regular auricular rhythm and the P variations are placed throughout at regular intervals. The

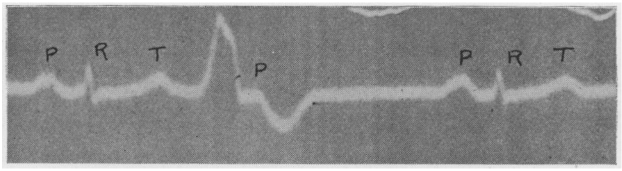

FIG. 7.

A single premature contraction arising in the ventricle. Two normal beats are shown, and are represented by P, R and T variations. The first is followed by an abnormal ventricular complex, of which the first phase is directed upwards and the second downwards. The sequential auricular contraction falls in the centre of the ventricular contraction, and is represented by a wave on the downstroke. This type of premature beat is recognized as one arising in the basal or right portion of the ventricular musculature. ($\times \frac{2}{3}$.)

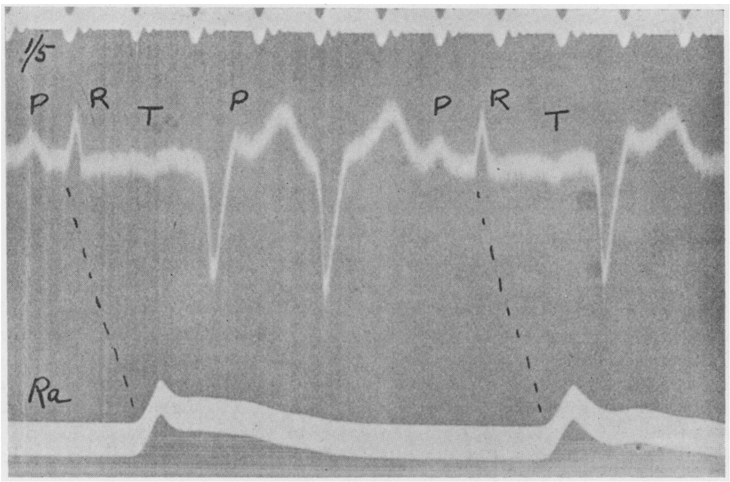

FIG. 8.

Shows premature contractions of the same type as those illustrated by fig. 6. The two figures are from the same case. A radial curve is also included. The premature contractions are more frequent and occur in groups. The figure is given to illustrate two points. First, to show the absence of effect of the abnormal ventricular beats upon the radial pulse; secondly, it is given for the comparison of the outlines of the first two abnormal ventricular complexes. They are not quite similarly shaped, and this is due to the fact that the sequential auricular contraction falls upon the first abnormal ventricular complex, and that the second is free from this complication.

ventricular complex, on the other hand, is no longer of normal form, but varies markedly from it; it may be of many shapes. Usually the normal P variation and the abnormal ventricular complex fall together and superimpose. The shape of the ventricular complex gives a clue to the actual point of the ventricular muscle from which such a beat has arisen; it is possible to obtain approximate experimental duplicates of such curves, but at present the localization is imperfect (figs. 6—9).

In the preceding paragraphs we have considered two of the commonest types of pulse irregularity met with clinically—the premature auricular and ventricular contractions (the auricular and ventricular extra-systoles, as they have often been termed). We may now discuss a rarer form of disturbance.

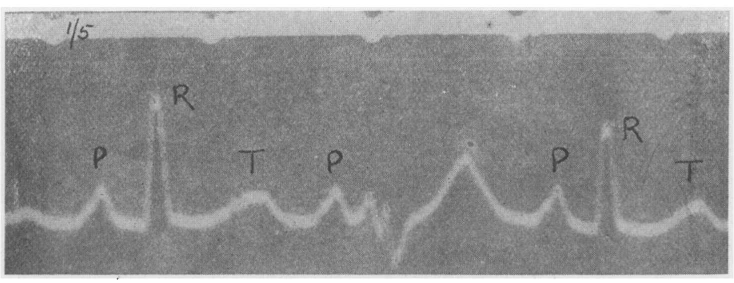

FIG. 9.

An electrocardiographic curve showing a single premature contraction of the ventricle. The first cycle is normal, consisting of P, R and T variations, and so is the last. The sequential auricular contraction, the middle P of the figure, is followed by an abnormal ventricular complex. This abnormal complex represents a ventricular contraction which is not a response to the preceding auricular contraction. This is known from the shape of the curve. It is also evident from the relative shortness of the interval between its commencement and the commencement of the preceding P. From a dog.

A Form of Paroxysmal Tachycardia.—Not infrequently one meets with patients who are the subjects of a well-defined and specific type of paroxysmal tachycardia. The pulse, while beating at a normal rate, becomes abruptly accelerated to rates approaching 150 to 200 beats per minute. The new rhythm is regular, and may be continued for shorter or longer spaces of time (from a few seconds to weeks or even months). It terminates, as it started, quite abruptly; an intervening pause is felt or recorded, and the normal rhythm immediately returns.

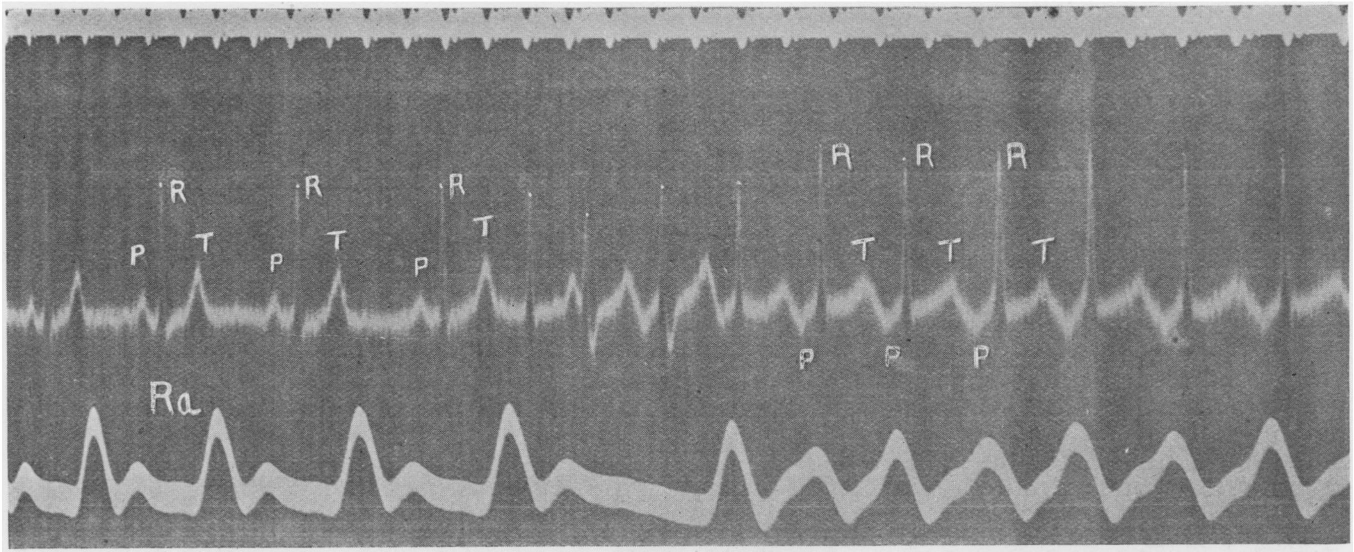

FIG. 10.—An electrocardiogram and radial curve from a case of paroxysmal tachycardia, arising in the lower levels of the auricular musculature. The curve starts with four cycles belonging to the normal rhythm. Each cycle is represented by P, R, and T variations. The paroxysm starts in three curious and anomalous beats, two of which have little effect on the radial curve. When fully established, the paroxysmal beats are represented in the electrocardiogram by a normal ventricular complex, R and T. The shape of these ventricular complexes indicates that the paroxysmal beats have originated from the supra-ventricular portion of the heart musculature. Each ventricular complex is preceded by an inverted P, showing that the contraction in the auricle has taken an abnormal course. It has travelled from below upwards, instead of from above downwards. The paroxysm originated, in all probability, in the neighbourhood of the auriculo-ventricular node.

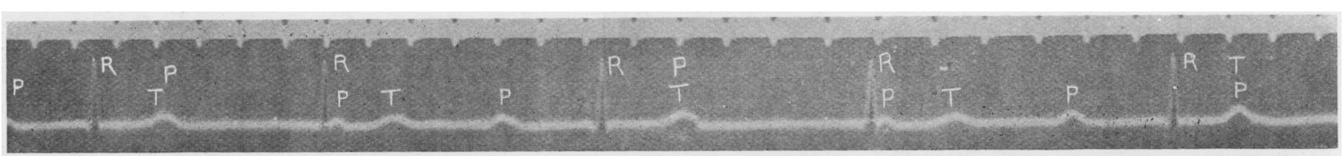

FIG. 14.—An electrocardiogram, showing the last stage of heart-block; complete dissociation of the auricular and ventricular rhythms. The ventricular beats, R and T, are placed at regular intervals. The rate is approximately 50 per minute. The auricular contractions, P, also occur at regular intervals; the rate is approximately 78. The summits, P, fall with haphazard relationships to the ventricular complexes; frequently they fall with them; in fact, each ventricular contraction of the curve is complicated by the simultaneous occurrence of an auricular systole. The P variations fall with the ventricular complex at various points, and the auricular and ventricular representatives are superimposed one on the other. $(\times \frac{7}{10\cdot 5})$.

Galvanometric examination of such patients has shown that the fast rhythm of the paroxysm is made up of a number of those beats which we have already examined—namely, premature contractions. Further, it has shown that the paroxysms may arise from a number of foci in the heart muscle, from one or other ventricle, from the junctional tissues, or the auricle itself. The new rhythm has arisen in every case as yet examined from a point in the musculature other than that in which the normal pacemaker lies. This is known by the shape of the electric complexes, auricular or ventricular respectively. In brief, the type of paroxysmal tachycardia referred to is the result of new and pathological impulse formation at an abnormal point. The new rhythms are *ectopic* in origin. It will suffice if a single instance is given (fig. 10).

Auricular Fibrillation.—The commonest of all irregularities of the human heart is that which has been termed *delirium cordis.* It is an

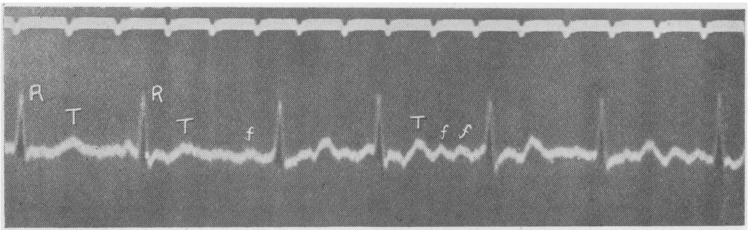

FIG. 11.

An electrocardiogram from a case of fibrillation of the auricle. The ventricular beats are represented by distorted complexes, R and T. The shape of the complexes indicates the supraventricular origin of the impulse creating them. Preceding the ventricular complex there is no regular P variation, representative of auricular contractions under normal circumstances. On the other hand, such P variations are replaced by a series of irregular oscillations, which run throughout the whole curve. They are marked *f f.* These oscillations originate in the auricle, and they produce the distortion of the T variations, which is noticeable in this figure. ($\times \frac{2}{3}$.)

irregularity of extreme grade; small and large beats are mixed together in the greatest confusion and at widely divergent intervals. It is especially associated with rheumatic heart disease, and with the widespread and degenerative cardiovascular changes of advancing years.

Galvanometric examination of patients afflicted in this manner has shown that we are dealing with a perfectly definite and a single and specific disorder of the heart's mechanism. It has shown in the most conclusive fashion that the mechanism is one which experimentalists have termed "auricular fibrillation." Auricular fibrillation is a condition in which the normal and co-ordinate contraction of the auricle, starting from the pacemaker, is replaced by an inco-ordinate condition, in which the auricle remains in diastole, and in which the whole of its musculature is in a state of subdivided activity. It appears as if impulses are initiated in many foci in its walls, and as if these impulses give rise to a turmoil of confused and interfering contractions, no single one of which is effective in expelling the auricular contents. It is from the auricular musculature, thrown into this disorder, that haphazard impulses escape to the ventricle. They escape irregularly, and consequently the ventricular contractions follow each other irregularly. The electric effects in fibrillation may be divided into the two usual components, the auricular and ventricular. The auricular effects consist of a number of rapid and irregular oscillations. One of the striking features of these

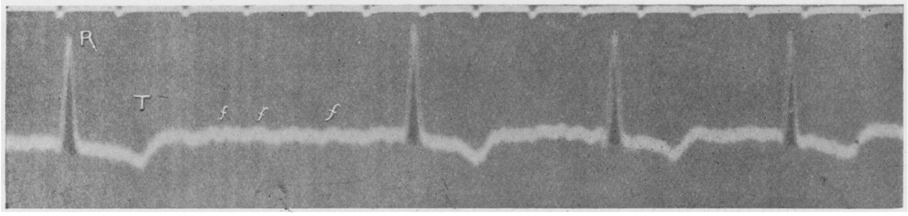

FIG. 12.

An electrocardiogram of a case of auricular fibrillation. The ventricular beats, R and T, are placed irregularly in the curve. The shape of T is noteworthy; it is of the inverted type. The inversion is often held to indicate a severe myocardial lesion. The absence of the normal auricular variation, P, before each ventricular complex is striking. The oscillations which replace the normal representatives of auricular systole are less marked than in the preceding figure, but are quite distinct. ($\times \frac{2}{3}$.)

oscillations is their continuation throughout the whole cardiac cycle, a fact in accord with our knowledge of fibrillation. They completely replace the P variations of the normal rhythm. The ventricular portion of the curve is constituted by complexes consisting of variations R and T, complexes which are placed at irregular intervals. From the shape of the ventricular complexes we know that the ventricular beats have arisen as a result of impulses reaching them along the normal paths; this is as we should expect, knowing as we do that the impulses are generated in the auricle (figs. 11 and 12).

Heart-block.—Another disturbance of the cardiac mechanism, which is by no means so uncommon as was originally supposed, and which is excellently portrayed by electrocardiographic curves, is heart-block. You know that the ventricle receives its impulses from the auricle through the recently discovered tract of tissue known as the auriculo-ventricular bundle. It often happens that disease hinders the conduction of these impulses in varying degree, and such obstruction often leads to very grave circulatory conditions. The several grades of heart-block are as follows:—

(1) The earliest sign of impaired function is manifested by a prolongation of the interval which separates the commencement of auricular and ventricular systoles, the P—R interval, as it is termed, in the electric curve.

(2) At a later stage there may be a failure of response rather than a delay of it; a ventricular response to auricle is completely missed at intervals.

(3) Further stages consist in more frequent ventricular silences, so that the auricle beats two, three, or more times as frequently as the ventricle.

(4) The final stage is one of complete dissociation of the auricle and ventricle, each beating regularly and of its own accord, independently and at different rates (figs. 13 and 14).

In the preceding paragraphs I have given you a few of the more simple forms of cardiac disorder in illustration of the galvanometric method, and I do not propose to exemplify the subject further. But it should be understood that the knowledge which the instrument affords us does not end here. I have not touched at all upon a wide field—the examination of hearts in which the ventricle beats regularly and in which the sequence is normal. It is perhaps premature to speak of them in a paper which merely pretends to outline the subject; but it is only fair to the instrument to state that it promises well in this direction. Those who are specially studying the electrocardiogram see that in the near future it may permit of the diagnosis of the auricular hypertrophy of mitral stenosis, and, as a consequence, the valve lesion itself, at so early a period of the life-history of the disease that the ordinary physical signs are wanting. There is also very suggestive evidence that it will supply us with more certain means than we enjoy at present of ascertaining and dissociating hypertrophy of one or other ventricle. These questions may be left for a future occasion.

I may conclude by summarizing the present position of the galvanometer in its relationship to the practice of medicine.

A SUMMARY OF THE RELATIONSHIP OF ELECTROCARDIOGRAPHIC WORK TO THE PRACTICE OF MEDICINE.

An estimate of the practical value of a single method of physical examination is at no time easy, and it is especially difficult when we deal with a method which is still in its infancy. In offering my own impressions of the relationship of the electrocardiographic methods

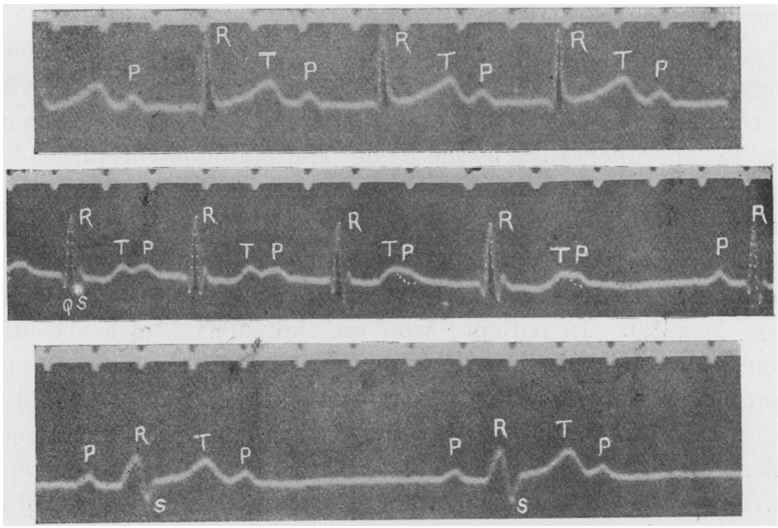

FIG. 13, *i*, *ii* and *iii*.

Three clinical curves to illustrate stages of heart-block. In fig. 13, *i*, the heart is beating regularly and the sequence is normal, in so far as each ventricular contraction, R and T, is preceded by an auricular contraction, P. The curve is nevertheless abnormal; the P—R interval is increased from the normal 0·12 to 0·17 sec. up to 0·3 sec. Fig. 13, *ii*, is from a case of mitral stenosis on digitalis. It is an example of dropped beats. The ventricular complexes are represented by the variations, Q, R, S and T, and in the early stages of the curve each ventricular beat is preceded by an auricular contraction, represented by P. It is to be noted that as the curve proceeds the P—R interval gradually increases until P falls back and is superimposed upon the preceding variation, T, of the ventricular contraction; the interval, P—R, for this cycle is nearly 0·3 sec. Up to this point the auricular impulse has had increasing difficulty in reaching the ventricle; the dropped beat is the final expression of this hindrance. At the end of the figure the next response of ventricle to auricle is shown. After the long rest the P—R interval decreases markedly. Fig. 13, *iii*, is from a case of heart-block in which the ventricle is responding to alternate beats of the auricle. The auricular complexes, P, are twice as numerous as the ventricular complexes, R, S and T. The curve is remarkable in that it shows a prematurity of alternate P variations, an early occurrence of the auricular contraction immediately following each ventricular contraction. The explanation of this phenomenon is unknown. ($\times \frac{2}{3}$).

to the practice of medicine, let it be understood that I give them as they appeal to me at the present time and after several years' study.

I should do wisely, I think, if I placed in the foreground, not the method itself, but the general conclusions which have been arrived at as a result of its employment, confining attention to those facts which have an immediate influence upon our conceptions of pathological conditions. Regarded from this point of view, our attention concentrates upon two conditions, which are usually referred to as *delirium cordis* and paroxysmal tachycardia respectively.

As a result of investigations carried out with the galvanometer, we are now in a position to assert in the most positive fashion that what has been termed in the past delirium of the heart is, in fact, a condition known to experimentalists by the name "fibrillation of the auricle." The clinical importance of recognizing this disorder of the cardiac mechanism can scarcely be exaggerated. It is directly accountable for 50 per cent. of all irregular pulses as they are encountered in a general out-patient department, and for an even higher percentage in the wards of a general hospital. In patients who are the subjects of heart affections attributable to a rheumatic infection, and in elderly patients who succumb as a result of progressive sclerotic myocarditis, the final breakdown is often, if not generally, heralded by the onset of this curious, distinct, and easily recognizable mechanism. The importance of identifying it is obvious, not only on account of its universality, its profound influence upon the life-history of the heart affected by it, but equally because, being a mechanism *sui generis*, it reacts to cardiac drugs in a specific manner. This is not the place in which to refer to the disorder in greater detail, but only to emphasize the imperative need of an acquaintanceship with the condition, and to claim for the galvanometer its final isolation and analysis.

I pass to the second condition, namely, paroxysmal tachycardia. Formerly it was regarded as of obscure origin, and frequently attributed to an affection of the cardiac nerve-trunks or their connexions. Now we possess clear evidence that cases which fall within this category may be placed in several distinct classes. Of these classes, two are peculiarly striking. In the one, the paroxysms of tachycardia consist of temporary crises of auricular fibrillation. There are paroxysms of rapid heart action, in which the ventricular beats follow each other irregularly. In the other form, which I have already briefly described, the paroxysms depend upon the awakening of new impulse formation in the heart musculature, and in some fixed point at a distance from the normal seat of impulse formation. It has been ascertained that the attack is the result of a temporary dislocation of the site of the *primum movens ;* or, perhaps, as it may be expressed more correctly, it is caused by the extinction of the rhythm of the normal pacemaker at the development of a new and more rapid rhythm in a point some distance removed from that which originates the normal rhythm. For the elucidation of these facts we are indebted to the new method. And, it may be stated in parenthesis, that our knowledge of the actual site of origin of the normal mammalian heart rhythm is largely referable to the same source. The normal rhythm of the heart arises, as we now know, from a small area of the right auricle immediately abutting upon the entrance of the superior vena cava.

I have placed these additions to our general knowledge in the forefront of the account rendered by the galvanometer, because they must necessarily and immediately modify our conception of, and our attitude towards, many clinical conditions, and because they form additions to the chapter of cardiovascular pathology which we can ill afford to neglect. Even a summary perusal of the multitude of the newly acquired facts furnished by the instrument has been impossible in the time at our disposal, and in this brief account these isolated examples have been stressed, not only because I am in a position to speak with a first-hand knowledge of them, but because they appeal to me as constituting generalizations, which cannot fail to receive general clinical application in the near future.

In closing an outline of the general conclusions in respect of which the new method debits us, we cannot lose sight of its important bearing upon other and more strictly clinical methods of examination. It may be stated that the galvanometer has already substantiated the great bulk of the facts previously acquired by means of the polygraph. It is true that it has at times led to conclusions at variance with previous conceptions, but the point which should be specially emphasized is that the galvanometer shows in the most unequivocal manner that we are fully justified in accepting the present-day interpretation of the vast majority of venous pulse records; and that the older method yields analyses of the heart mechanism which are almost always upheld if submitted to the arbitration of this new instrument; and the importance of this conclusion will be more evident when it is remembered that the galvanometer is essentially a laboratory instrument, while the polygraph accompanies the clinician to the bedside of his patient. From this point of view the polygraph may be regarded as a go-between, obviating the necessity of transplanting a cumbersome apparatus.

Of the more immediate benefits conferred by the instrument I speak more hesitatingly. The size, weight, and cost of the galvanometer and its fittings materially restrict its sphere of usefulness. It has to be maintained as a fixed installation, and it is difficult to see how it can ever leave the immediate precincts of the laboratory or hospital. These disabilities are reduced to some extent by the possibility of bringing a relatively large area within its immediate working sphere. The instrument may be connected by properly insulated wire to any ward or room within a convenient range. A single outfit will consequently supply a single institution or several institutions in its immediate vicinity. As a part of the equipment of a modern hospital or physiological laboratory it is already almost a necessity. Once installed it gives a ready and infallible analysis of the sequence of contraction of the cardiac chambers. A few minutes (three or five) places the clinician in full possession of all the necessary data for the analysis of an arrhythmia in all but exceptional instances, and the data are of the most accurate nature. In several respects it presents material advantages over the polygraphic method. Its superiority as an instrument of precision is unquestioned, a quality which is dependent upon the directness of the method. A venous record is an expression of an effect of the heart upon venous inflow; the electric curve is an expression of the heart-beat itself. A second and considerable advantage consists in the ease with which the majority of the records are read; polygraphic curves often require minute and often tedious measurement; the majority of electrocardiograms may be read at first sight. In the third place it gives valuable information, not only as to the instants at which auricle and ventricle contract, but as to the direction which the contraction waves pursue in individual chambers, and consequently as to the points at which such contraction waves arise in the chambers. In brief, it is a weapon which has no equal for precision where an analysis of the cardiac mechanism is required; it takes precedence of all other methods where evidence is conflicting; the information obtained is secured with a minimal expenditure of time.

The comparison of one method of physical examination with another is always difficult, but restricting comparisons to hospital patients, I have little hesitation in stating that in the routine examination of the heart patients the galvanometer method affords, or will afford in the near future, information of equal or greater value than any other single method at our disposal, be it instrumental or subjective. It must be allotted at least an equal place with percussion and auscultation, with sphygmomanometry and radiography ; and in this respect it has this to be said for it, that the information it offers it offers definitely, the information it withholds it withholds as definitely ; it is, in fact, a method of exactitude, a method of precision.

DISCUSSION.

The CHAIRMAN (Sir William Allchin) said it was unfortunate that the President of the Section was unable to be present, for Dr. Mitchell Bruce was among the few who were able to make remarks at all pertinent to such a contribution as Dr. Lewis had just delivered, as such work was naturally confined to a few; and one could not help admiring the very lucid way in which Dr. Lewis had put forward a very complicated subject. One also must realize the amount of work he must have undertaken to enable him to speak in so clear a manner on the subject. This work contributed from another direction towards what in so many quarters was being done to improve diagnosis and investigate with greater precision the phenomena of disease.

Dr. GOSSAGE said it was difficult to speak on the subject, because he, and probably all others in the room, had had no experience of working with the instrument which Dr. Lewis had described. Once he had the great advantage of seeing Dr. Lewis take an electrocardiogram from one of his (Dr. Gossage's) patients ; an obscure case, on which the record threw much light. Probably most of the Fellows would agree with the conclusions at which Dr. Lewis arrived. The evidence given in the paper was only a small part of what the author and others had in the background, evidence which completely justified everything which had been said. The question as to the employment of the electrocardiogram as a clinical instrument was involved in more difficulty ; it required much education before the instrument could be used; moreover, it was an instrument only suited to an institution, to which the patient must be brought. The apparatus could not be possibly conveyed to the patient.

Dr. ALEXANDER MORISON said he felt the same inability to criticize the excellent paper which had just been heard, but wished to express his admiration of the work which Dr. Lewis had done. That gentleman had excluded from his paper all controversial matter, and he (Dr. Morison) had no intention of importing any. But he would be glad if, in his reply, Dr. Lewis would make clear the circumstances which caused him positively to assert the necessary initiation of a delirium cordis in the auricle. One knew that in the ordinary examination of a delirious ventricle one had a large number of aborted diastolic periods, and as the blood must go somewhere, there was probably an accumulation in the auricle. He was still inclined to regard the auricular comparative inactivity as due more to a mechanical over-filling than the arrhythmical ventricular action due to a rapid multiplication of the stimulating impulses arising in the auricle. All would agree that no more important work had been done in the matter of the minute anatomy of the heart than had been done of late years in elucidating the functions of the conducting apparatus.

He did not know that all the conclusions which had been based upon it were sufficiently sound to warrant an ex cathedra interpretation of them. With regard to the sino-auricular node or pacemaker, he had seen that part of the heart disabled by sarcomatous growth without disturbing the rhythm of the ventricle. He did not know whether Dr. Flack's results were generally accepted, but the effects of its destruction of that node supported his own observations and did not seem to be followed by the consequences one would anticipate from current interpretations of its function. It was argued there was some similar source of origination of impulse elsewhere, as the destruction of the node did not seem to have much disturbed the function of the heart. He would like to hear the grounds on which Dr. Lewis was able to state, from his electrograms, that a case of delirium cordis necessarily commenced in the auricle.

Dr. LEWIS, replying to Dr. Morison, said that the evidence for auricular fibrillation in man was a long story, and that he would content himself with a brief résumé of the main points in that evidence. The picture which obtained in cases of so-called delirium cordis was always of the same character; the records were always similar. He based this statement upon the electrical examination of sixty cases, and upon a large number of cases collected from other papers. With regard to the shape of the ventricular complexes, they were of normal outline, consequently it could be concluded that individual beats originated from a supra-ventricular portion of the heart—i.e., from the auricle or from the tissues which joined the auricle and ventricle. That contention would be accepted by those who were acquainted with electrical work. All signs of auricular contraction had gone, and they were replaced in all cases by a series of oscillations which ran throughout the whole curve. One knew that the large variations marked R and T were due to the ventricle, and one might ask what the oscillations were due to. Their point of origin of those oscillations was clinched by the employment of special leads from the chest wall. Where there was mitral stenosis, and the right auricle was against the wall of the chest, one could identify the point of origin in that area of chest wall overlying the auricle itself, whereas one could get uncomplicated ventricular curves from the parts of the chest which overlay the ventricles. The oscillations were not representative of co-ordinate auricular contractions, but were the total result of the whole electrical changes occurring in a chamber in which the muscular activity was continuous and inco-ordinate. It was practically a diastolic auricle, but the wall of the auricle was continually active; it was flickering all over. Again, the comparison of the clinical with the experimental curves produced by auricular fibrillation in the dog had demonstrated that arterial, venous and electric curves were identical in one or the other condition. Recently he had had several opportunities of seeing the same irregularity of the heart in the horse, and in one case of obtaining records from this animal; he had opened the chest and had seen the fibrillation on two occasions. The ventricle was beating rapidly (50 to 150 beats per minute, as opposed to the normal rate of 35 to 40 beats per minute) and extremely irregularly in the animals upon which these observations were made.